Integration and Organization of Information for Display

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ABSTRACT
In this poster we present several methods for abstracting data into information and then integrating and organizing it for the purpose of display. We use an example from analysis of pilot-automation interaction to illustrate some of the underlying concepts.

Categories and Subject Descriptors
H.1.1 [**Models and Principles**]: User/Machine Systems–*Human factors.*

General Terms
Human Factors

Keywords
Abstraction, Integration, Organization, Information Presentation.

1. INTRODUCTION
Modern information systems, such as networks, database systems, and decision support systems, contain and provide extensive volumes of data that are available for analysis and display. In aerospace applications, with the introduction of Integrated Vehicle Health Monitoring (IVHM) technology, even wider sensor coverage will be available, allowing for almost real-time computations of expected (i.e., learned) values and their relationship to observed values, computations of trends, and generation of composites of variables [4]. The question of how to provide this wealth of data and information—so as to aid users in the process of monitoring, analysis, making decisions, considering consequences, and, ultimately, taking the appropriate action—is the focus of this research. To this end, consider the pyramid in Figure 1. It has four levels: (1) *extraction* of signals from the system and its environment and turning them into data; (2) *abstraction* of data into information; (3) *integration* of information into geometrically coherent structures so as to show meaningful relationships, supporting knowledge and understanding; and (4) *organization* of these information structures to create order and wholeness.

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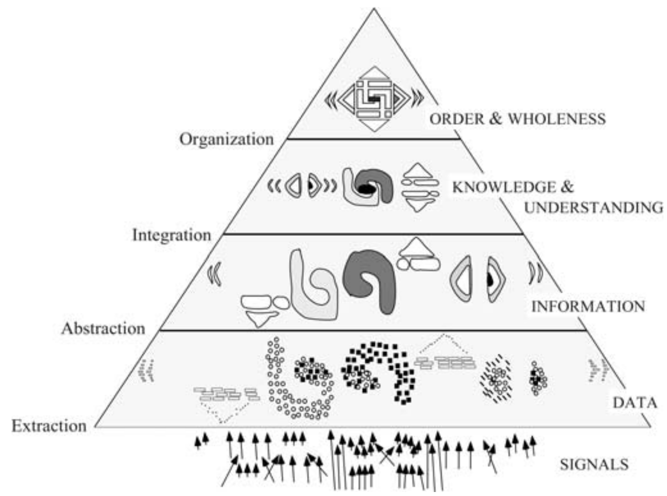

Figure 1. From signals to wholeness.

We use this hierarchical structure to consider the design of information presentation and guide the process of achieving level 4, order and wholeness. Similar multi-level hierarchies for describing the structure of man-made systems have been formulated in architectural design and urban planning [1] and for representing the context in which supervisory decisions are made in process control (e.g., nuclear power) [5]. What follows is the application of this approach to the design of a visual display to analyze pilot-autopilot interaction.

2. PILOT-AUTOPILOT INTERACTION
The data described here is from a study of crew interaction with the automatic flight control system of the Boeing 757/767 aircraft where every visible change in the aircraft control modes, along with each setting relating to the flight control system status (e.g., waypoints and altitude values selected by the pilot), was recorded. Likewise, every visible change in the operational environment (e.g., a new instruction from Air Traffic Control) was recorded, along with related variables such as the aircraft altitude, speed, and distance from the airport. Overall, the dataset consisted of more than 120,000 data points [3].

2.1 Abstraction
We were interested in identifying the relationships that exist between the state of the operating environment (considered as the independent variables—X's) and pilots' actions and responses as represented through their interaction with the automatic flight control system's modes and settings (dependent variables—Y's). We used canonical correlation to analyze the relationships

between the (multiple) independent and dependent variables. The computation revealed several pattern-like relationships between independent and dependent variables. Each of these patterns can be reduced to a bivariate correlation, which is visually inspected using a familiar bivariate scatter diagram.

The canonical correlation analysis identified four sets of patterns that were statistically significant ($r = 0.95, 0.88, 0.81, 0.72$; $p<0.001$). The outside ring of Figure 2 shows the first set ($r = 0.95$), containing two patterns—one positive and one negative—depicted by dark and white bars, respectively. For example, the positive pattern (dark bars) in the outer ring of Figure 2 indicates that for all independent variables (X's) *when* aircraft altitude is high (above the average of 13,000 feet), the phase of flight is "descent," the Air Traffic Control facility is "approach control," and the vertical clearance is "descend to altitude," *then* the corresponding modes and settings selected by the pilots are most likely to be: autopilot "engaged," pitch mode in "flight level change," and thrust mode in "cruise."

2.2 Organization

The above-mentioned $r = 0.95$ set is only one of four sets of patterns identified by the canonical correlation analysis. And while it is possible to present each set separately, we decided to combine all sets within a single graph in order to see the overall "story" of how the patterns relate to one another and cover the range of all possible variables. In developing the notions of integration and organization, we are using the properties and

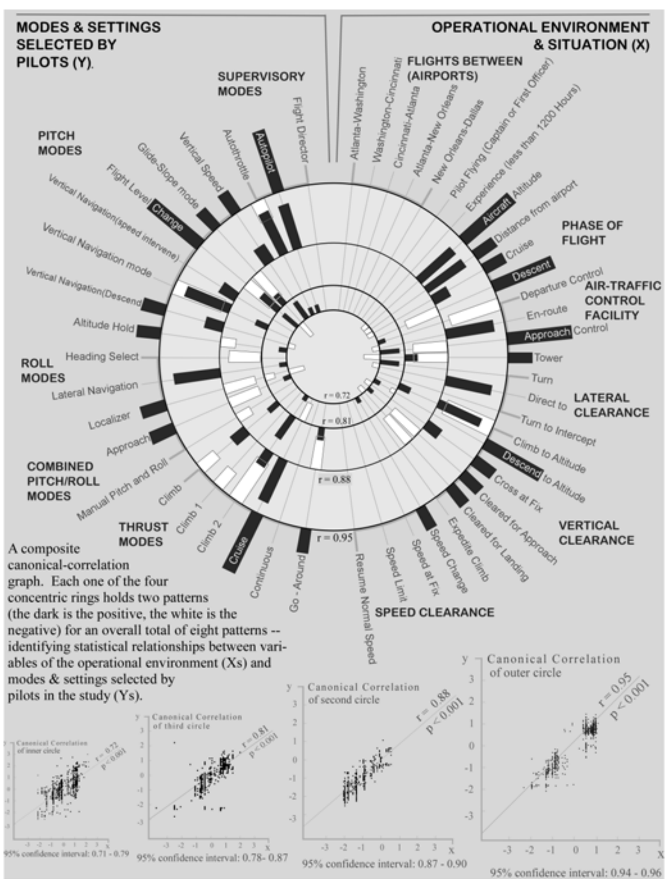

Figure 2. Concentric rings embodying all four pattern sets.

processes described in Alexander's theory of centers [2]. The theory describes 15 heuristic properties that help create integration and organization in a design. The first property, *level of scale*, concerns the different ranges of sizes and internal coherence of "centers" within a given design. Thus, after realizing that we have several different levels of statistical strength (significance) among the four sets (0.95, 0.88, 0.81, and 0.72) it became geometrically advantageous to organize them as concentric rings according to their statistical strength.

2.3 Integration

Several properties in Alexander's theory of centers have a strong integration aspect. One of them is *boundary*, which serves to tie a given center with its surrounding space (as a colonnade marks the end of a building and the beginning of the garden, and ties them together). In Figure 2, the variable labels form a boundary between the inner world of data (values, significance, etc.) and the outer operational world with its terminology and relationships. Another property that serves to couple and integrate centers is *interlock*. This property marks a situation where spaces (or centers) are hooked into their surroundings, causing fusion and coupling. In Figure 2, note the cases where there is an interlock between black and white bars of the same variable (e.g., "climb to altitude" and "Vertical Navigation mode"), indicating a strong effect that shows up independently in adjacent rings. Other properties that were utilized in Figure 2 include *contrast* (between black and white bars) and *gradients* (in the magnitude of bar sizes, which, for the purpose of this display, was abstracted into three categories—strong, weak, and none). *Alternating patterns* and *echoes* present in the ray-like spokes guide the reader's eye as the rings (and variables) become smaller and merge into the *void* in the center of the graph.

3. SUMMARY

In this paper we briefly discussed a conceptual framework for the process of representing and presenting information. Three processes were mentioned: abstraction, integration, and organization. While the topic of data abstraction in statistics, for example, is well defined and rests on a sound theory, the topic of information integration and organization is in its infancy. This is a serious shortcoming that is worthy of further research where concepts from art, practical design, and architecture are brought in and extended to the problem of information presentation.

4. REFERENCES

[1] Alexander, C. *Notes on the Synthesis of Form*. Cambridge, MA: Harvard University Press, 1964.

[2] Alexander, C. *The Phenomenon of Life*. Berkeley, CA: The Center for Environmental Structure, 2002.

[3] Degani, A. *Modeling human-machine systems: On modes, error, and patterns of interaction*. Unpublished doctoral dissertation. Georgia Institute of Technology, 1996.

[4] Iverson, D. Inductive System Health Monitoring. *Proceedings of the 2004 International Conference on Artificial Intelligence* (IC-AI'04), 2004.

[5] Rasmussen, J. *Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering*. New York: North-Holland, 1986